F-PCM: A fragmentation-based power control MAC protocol for IEEE 802.11 mobile ad hoc networks

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Summary

A great deal of research has been directed toward reducing energy consumption at the 802.11-based MAC layer for mobile ad hoc networks (MANETs). There exists an approach that uses maximum power during the RTS-CTS exchange and computes the required amount of power in order for DATA and ACK messages to reach the receiver and sender. It, however, does not consider the existence of an interference range (IR), or often called a carrier sensing zone. In order to address the problem, an existing approach forces nodes, located within a sender’s carrier sensing zone, to defer their transmission trials in order to avoid collisions at the sender. It, however, does not consider possible collisions at the receiver, which can result in frequent retransmissions and hence greater energy consumption. Therefore, we propose an efficient protocol called Fragmentation-based Power Control MAC (F-PCM), which utilizes the fragmentation mechanism of the IEEE 802.11 MAC protocol so as to avoid collisions at senders as well as those at receivers. Through extensive simulations, our F-PCM has performed better in terms of providing a higher throughput and incurring lower energy consumption. This is particularly advantageous in a dense mobile network environment where collisions are more severe. Copyright © 2006 John Wiley & Sons, Ltd.

1. Introduction

Mobile ad hoc networks (MANETs) [1] are multi-hop networks in which mobile nodes cooperate to maintain network connectivity and perform routing functions. In particular, since mobile nodes in MANETs spend a great deal of energy in forwarding packets, efficient techniques to minimize energy consumption of nodes are definitely needed. Current research on saving a node’s energy is by switching the nodes into a ‘sleeping mode’ whenever they do not participate in routing the forwarded packets [2–4]. However, energy conservation can also be pursued by dynamically adjusting the transmission range of nodes in accordance to the distance between two communicating nodes over a given wireless link. This is, therefore, different from those schemes that rely on fixed transmission ranges [5,6]. It is possible to combine these two approaches in order to better conserve energy consumption.

In the Basic Power Control MAC Protocol (BASIC) scheme [5], request-to-send (RTS) and clear-to-send (CTS) packets are transmitted with a maximum...
amount of power $P_{\text{max}}$. The RTS-CTS handshake is used to determine the transmission power for the subsequent DATA and ACK packet transmissions. The BASIC protocol, however, did not consider the existence of the interference range (or the so-called carrier sensing zone)\(^1\). According to the IEEE 802.11 standard, although nodes located within the interference range of a transmitting node cannot succeed in decoding the received signal, nodes should defer their transmissions of DATA during an interval denoted by Extended Inter-Frame Space (EIFS). In addition, nodes which have deferred their transmissions because they are located within the interference range of a sender’s RTS are now out of the interference range when the sender transmits its DATA packet with reduced power.

Therefore, when any of these nodes starts to transmit at the power level $P_{\text{max}}$ after its EIFS expires, this transmission will cause a collision with the ACK packet transmitted by the receiver. This results in throughput degradation and higher energy consumption.

A Power Control MAC Protocol (PCM)\(^6\) modifies this BASIC scheme so as to minimize the probability of such collisions. The sender and receiver nodes transmit the RTS and CTS packets, as usual, with maximum power $P_{\text{max}}$. Nodes in the carrier sensing zones of the sender and receiver nodes stop their transmissions for an EIFS period when they sense the signal, but are not able to decode it. The sender node generally transmits with the minimum necessary amount of power, as in the BASIC scheme. However, in order to avoid collisions with packets transmitted by the nodes in the carrier sensing zone of a sender’s RTS, the sender transmits the DATA packet at a maximum power level $P_{\text{max}}$ during a short interval, which operates periodically. Note that PCM, however, does not prevent collisions completely. In particular, packets from nodes in the carrier sensing zone of a receiver’s CTS can still cause collisions with DATA being received by the receiver.

In this paper, we attempt to reduce collisions at senders as well as those at receivers. We propose an efficient power control MAC protocol by taking advantage of the fragmentation technique used in the IEEE 802.11 MAC layer, called fragmentation-based power control MAC (F-PCM). A large DATA packet is fragmented into several small fragments and the ACK packet corresponding to each fragment is transmitted at maximum power. Therefore, nodes which seem to produce a collision at the receiver become informed of the ongoing DATA transmission. In addition, in order for nodes within the carrier sensing zone of a sender to defer their transmissions, the sender increases its transmission power up to the maximum amount for a short duration at the beginning of each fragment transmission. As a result, during the transmission of a large DATA packet, we can reduce such collisions at senders as well as those at receivers.

The rest of this paper is organized as follows: In Section 2, we provide information on the IEEE 802.11 MAC protocol whose RTS–CTS–DATA–ACK exchange is used in F-PCM, PCM, and BASIC. We state the disadvantages of BASIC and PCM in Section 3. Our F-PCM technique is described in Section 4. In Section 5, we evaluate the performance of F-PCM. Finally, some concluding remarks and plans for future work are presented in Section 6.

2. IEEE 802.11 MAC Protocol

Simple Carrier Sense Multiple Access (CSMA) protocols\(^7\) cause well-known hidden and exposed terminal problems due to the sensitivity to nodes’ locations. As shown in Figure 1, both nodes S1 and S2 are hidden from each other as they are not within direct transmission range and are unaware of the presence of each other. This can cause a collision at R1.

The exposed terminal problem refers to the inability of a node to transmit due to an ongoing transmission by neighboring nodes. As shown in Figure 1, if a transmission from node S1 to another node R1 is already in progress, node S3 cannot transmit to node R2 until the end of the transmission. This is because it concludes that its neighbor node S1 is transmitting and hence its own transmission can interfere with the on-going one. In this context, node S3 is said to be exposed to S1. Those hidden and exposed terminal problems significantly reduce the network throughput when the traffic load is high. For the purpose of resolving the hidden terminal problem, various approaches such as multiple access with collision avoidance (MACA)\(^8\) have been developed by introducing the exchange of RTS and CTS before the transmission of data. Furthermore, due to the absence of a mechanism that enables reliable data transmission in MACA, the IEEE 802.11 MAC protocol uses the Distributed Foundation Wireless MAC (DFWWMAC) protocol\(^9\). DFWWMAC adds the transmission of the ACK packet to this basic MACA protocol.
protocol, resulting in a four-way exchange, RTS–CTS–DATA–ACK. The receiving of the ACK packet means the completion of a successful transmission. As shown in Figure 1, when a receiver receives the RTS packet from a transmitter successfully, it sends a CTS packet to the sender after a Short Inter-Frame Space (SIFS) interval. All nearby nodes receiving either the RTS or the CTS packet maintain a Network Allocation Vector (NAV) which indicates the remaining time of the on-going transmission session.

In particular, the existence of the interference range (also called the carrier sensing zone) makes the MAC protocol more complex. Nodes within the interference range of a node transmitting a data packet cannot accept the received packet successfully because it is simply undecodable. Therefore, nodes within the interference range of an RTS-sending or a CTS-sending node simply defer their transmissions with their own NAVs set to the EIFS period as defined by the IEEE 802.11 standard.

In addition, IEEE 802.11 allows a large DATA packet, called MAC service data unit (MSDU), to be fragmented into smaller fragments in order to improve reliability, since a large DATA packet is more susceptible to channel error than a short one. If the MSDU size is greater than a given threshold (i.e., fragmentation threshold), the packet is permitted to be fragmented (See Figure 2).

### 3. Related Work

In general, it is assumed that most of the power control MAC protocols can transmit each packet with a different amount of transmission power. In this section, we describe the key behavior of BASIC and PCM.
Currently, some protocols (including F-PCM) are based on omni-directional antennas while others \cite{10,11} use directional antennas.

### 3.1. Basic Power Control

**MAC Protocol: BASIC**

In the BASIC scheme \cite{5}, RTS and CTS packets are transmitted with a maximum amount of power \(P_{\text{max}}\). The RTS–CTS handshake is used to determine the transmission power for subsequent DATA and ACK packet transmissions. There are two possible methods. In the first method, the sender node A transmits the RTS with \(P_{\text{max}}\). This RTS is received by the receiver with a signal level of \(P_r\). The receiver node B can calculate the minimum required transmission power level \(P_{\text{desired}}\) for the DATA packet, based upon the received power level \(P_r\), the transmitted power level \(P_{\text{max}}\), and the noise level at the receiver B. Node B then specifies this \(P_{\text{desired}}\) in the CTS packet it transmits to node A. Node A transmits the DATA packet using the power level \(P_{\text{desired}}\). In the second method, when the receiver node B receives an RTS packet, it responds with a CTS packet at the usual maximum power level \(P_{\text{max}}\). When the sender node receives this CTS packet, it calculates \(P_{\text{desired}}\) based upon the received power level \(P_r\) and the transmitted power level \(P_{\text{max}}\), by the following Equation (1),

\[
P_{\text{desired}} = \frac{P_{\text{max}}}{P_r} \times \text{Rx\_thresh} \times c \tag{1}
\]

where \(\text{Rx\_thresh}\) is the minimum necessary received signal strength and \(c\) is a constant. The sender node uses the power level \(P_{\text{desired}}\) to transmit the DATA packet. Similarly, the receiver uses the signal power of the received RTS packet to determine the power level to be used, \(P_{\text{desired}}\), for the ACK packet. Thus, the BASIC scheme uses the maximum amount of transmission power for the RTS and CTS packets, and only the necessary power levels for the DATA and ACK packets. This scheme, however, has a drawback. As shown in Figure 3, node A sends an RTS to node B, for which node B sends a CTS packet. Since these packets are sent at maximum amount of power, nodes X and Y, which are located in the carrier sensing zones of nodes A and B, respectively, will defer their transmissions for a sufficient period of time (i.e., EIFS duration) so as not to interfere with their RTS–CTS exchanges. However, for DATA and ACK transmissions, only minimum power is used. Hence, DATA transmitted by node A cannot be sensed by node X, and the ACK packet transmitted by node B cannot be sensed by node Y. If nodes X and Y try to transmit packets after their EIFS periods (their NAVs were set upon sensing the RTS or CTS packet) have expired, collisions would occur at node A, that is, any packet sent by node X would collide with the ACK sent by node B. Similarly, any packet sent by node Y would collide with DATA packet sent by node A.

### 3.2. A Power Control MAC Protocol: PCM

PCM \cite{6} improves the BASIC scheme in order to minimize the probability of such collisions at the sender nodes. The sender and receiver nodes transmit the RTS and CTS packets, as usual, with a maximum power \(P_{\text{max}}\). Nodes in the carrier sensing zones of the sender and receiver nodes set their NAVs to EIFS duration when they sense the signal, but are not able to decode it. The sender node generally transmits its DATA packet with the minimum necessary amount of power, as in the BASIC scheme. In order to avoid collisions with packets transmitted by the nodes in its carrier sensing zone, however, the sender node transmits the DATA packet with \(P_{\text{max}}\) periodically. Each duration using the maximum power must be larger than the time required for physical carrier sensing. Since the nodes in the carrier sensing zone defer their transmissions for EIFS duration if they are not able to decode the received signal, the transmission power for the DATA packet should be increased every EIFS duration. The changes of the power levels for the RTS–CTS–DATA–ACK transmissions are depicted in Figure 4. Thus, this protocol prevents collisions at the sender node. PCM achieves a throughput very close to that of the 802.11 protocol while using much less energy. As mentioned before, the key difference between the PCM and BASIC schemes is that PCM periodically uses \(P_{\text{max}}\) during DATA transmissions.

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4. Our Fragmentation-Based Power Control MAC Protocol: F-PCM

4.1. Motivation

Although the PCM protocol prevents collisions at sender nodes, the protocol still has the possibility of collisions at receiver nodes. Packets from the nodes in the carrier sensing zone of a receiver node’s CTS can still cause collisions with a DATA packet being received by the receiver. As shown in Figure 3, node Y is not located within the carrier sensing zone when node A sends its DATA packets to node B. If node Y transmits a packet after the EIFS timer (its NAV was set upon sensing the RTS or CTS packets) expires, the packet transmitted by node Y would collide with the DATA packet at node B.

To address this problem, we propose F-PCM which incorporates the fragmentation technique used at the IEEE 802.11 MAC layer. Like BASIC and PCM, F-PCM allows the sender and receiver to send RTS and CTS with $P_{\text{max}}$. Each data fragment is transmitted using the necessary amount of transmission power to reach the receiver. When the sender transmits each fragment, it utilizes a maximum amount of power for a short duration at the beginning of the fragment transmission. It aims to reduce collisions at the sender. Also, the ACK packet corresponding to each fragment is transmitted using the maximum amount of power, which forces the nodes such as node Y to reset their NAVs in order to avoid collisions at node B. It results in reducing the number of those collisions at a receiver as well as at a sender. The following section will provide more detail regarding how F-PCM works.

4.2. Description of F-PCM

First, we explain the operation of a sender and nodes in a carrier sensing zone of the receiver. The other nodes within the transmission range of the sender and receiver will follow the procedure of the IEEE 802.11 MAC protocol in order to set their NAV values.

4.2.1. Operation of a sender and nodes located within a carrier sensing zone of the sender

Basically, F-PCM takes advantage of the fragmentation technique used in the IEEE 802.11 MAC protocol. F-PCM operates similar to PCM in that the sender uses a maximum power $P_{\text{max}}$ for a duration of $20\,\mu$s from the beginning of transmitting a data packet after the exchange of RTS–CTS using $P_{\text{max}}$. In F-PCM, however, it operates in a fragment basis. In addition, when a node is located within the carrier sensing zones of other nodes, the node determines a new EIFS, denoted by $n_{\text{EIFS}}$, instead of the EIFS used by the IEEE 802.11 MAC. The small EIFS defined in the IEEE 802.11 standard allows nodes located within a carrier sensing zone of a sender to retry their transmissions after the expiration of the EIFS values, which can frequently produce collisions at the sender with the ACKs sent by a receiver. Therefore, F-PCM determines the $n_{\text{EIFS}}$ based upon the size of the fragment in order to defer the transmissions of the nodes, at least until a fragment is successfully sent to a receiver and the sender receives an ACK packet from the receiver (see Equation (2)).

$$n_{\text{EIFS}} = T_{\text{DATA,Fragment}} + T_{\text{ACK}} + 2 \times \text{SIFS} + 2 \times \text{aSlotTime}$$  \hspace{1cm} (2)

where SIFS and aSlotTime are defined in the IEEE 802.11 MAC standard and $T_{\text{DATA,Fragment}}$ and $T_{\text{ACK}}$ are the required times needed to transmit a fragment and an ACK packet, respectively.

Note that the nodes located within a carrier sensing zone will have to reset their NAVs to the $n_{\text{EIFS}}$ periodically, as long as there exists a fragment to be sent.
4.2.2. Operation of a receiver and nodes located within a carrier sensing zone of the receiver

In addition, we also apply the $n_{\text{EIFS}}$ values to the nodes located within a carrier sensing zone of a receiver. They set their $NA_V$s to the $n_{\text{EIFS}}$s upon hearing a CTS packet. When a receiver receives a DATA packet transmitted using the reduced power, the nodes may create a collision at the receiver with their transmissions (after the expiration of their current $n_{\text{EIFS}}$ values). Hence, whenever the receiver receives each fragment, it sends its ACK packet with $P_{\text{max}}$, which forces the nodes to reset their $NA_V$s to the $n_{\text{EIFS}}$s in order to avoid a collision with the next incoming fragment from the sender. Finally, the receiver does not need to use $P_{\text{max}}$ for the ACK packet corresponding to the last fragment. Since it is the last fragment for the large DATA packet, the nodes located within a carrier sensing zone of a receiver do not have a reason for deferring their transmissions additionally. Therefore, F-PCM allows the receiver to send its last ACK for the last fragment with the minimum amount of power needed in order to reach the sender.

4.3. Illustrative Example

As shown in Figure 5(a), nodes D and E exchange their RTS and CTS with $P_{\text{max}}$ before transmitting a DATA packet. Since nodes A and H are located within the carrier sensing zones of nodes D and E, respectively, they set their NAVs to $n_{\text{EIFS}}$ in order to defer their transmissions until a DATA-ACK exchange of a fragment is performed successfully without a collision. After the exchange of RTS-CTS, nodes D and E send their DATA and ACK packets with the required amount of energy to reach each other. Node D, however, uses $P_{\text{max}}$ for the RTS-CTS exchange and $P_0$ for the DATA and ACK packets. Nodes like node D set their NAVs to $n_{\text{EIFS}}$ after receiving the CTS packet and do not defer their transmissions until the DATA-ACK exchange is performed successfully.

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Fig. 5. Our proposed F-PCM protocol.
a maximum transmission power \( P_{\text{max}} \) for a duration of 20 \( \mu \text{s} \) from the beginning of transmitting each fragment. This forces node A to reset its NAV to \( \text{n}_{\text{EIFS}} \) in order to defer its transmission for the purpose of avoiding a collision at node D. Node E, which received a DATA packet from node D, also sends the corresponding ACK packet with \( P_{\text{max}} \), which forces node H to defer its transmission in order to avoid a collision at node E with the next fragment from node D. Node E, however, sends the ACK packet for the last fragment with the minimum amount of power because it should not defer node H’s transmission any longer. Figure 5(b) shows when to use the maximum power \( P_{\text{max}} \) during RTS–CTS–DATA(fragment)–ACK exchanges.

### 4.4. Discussion

F-PCM divides a large DATA packet into small fragments, each of which is independently transmitted as an encapsulated frame with a header and trailer. The header contains the physical addresses of the sender and receiver, and the trailer has a cyclic redundancy check (CRC) for the frame. When a large DATA packet is fragmented, there is a concern about the overhead when creating these headers and trailers for each fragment. This implies that nodes will consume more energy. Headers and trailers, however, are not very large and furthermore, F-PCM does not require many fragments. It is understood that the frame body (MAC Service Data Unit = MSDU) can be a maximum size of 2346 bytes, according to the IEEE 802.11 standard [9]. If the fragment size of 512 bytes is used, there are not many fragments for the MSDU. More importantly, although there exists additional information for F-PCM, it outperforms other protocols because it has fewer collisions and re-transmissions, as shown by the simulation results which are described in the next section. Note that F-PCM can be still applied to a DATA packet and the last fragment, which are smaller than 512 bytes.

### 5. Performance Evaluation

In order to estimate the performance of our F-PCM protocol, we used random topology for the variable number of nodes and we compared our F-PCM with BASIC and PCM in terms of the average throughput and the amount of energy expended in the network. In our simulation, the throughput is defined as the number of bytes successfully sent between the source and the destination nodes in an end-to-end manner. We randomly selected pairs of source and destination nodes, whose connection times are exponentially distributed.

The IEEE 802.11b DCF mode was used in the simulations as a basic MAC protocol of our F-PCM by varying some parameters such as fragment size. We used a network area of 1000 m \( \times \) 1000 m and varied the number of nodes between 10 and 50. We assumed a transmission range and a carrier sensing zone of 250 m and 550 m, respectively. In order to compute the amount of energy expended, we adopted the energy model used in Reference [12]. For other simulation parameters, we followed those of IEEE 802.11 standard [9]. We ran each simulation for 20 s with CBR traffic sources. The additional simulation parameters used in our experiments are summarized in Table I.

### 5.1. Fragment Size Determination

Since F-PCM takes advantage of the fragmentation technique, we attempted to find the best fragment size, taking into consideration its impact on the average end-to-end throughput and the amount of energy consumed. The result is the average taken from over 30 random network topologies. Various fragment sizes between 64 and 1024 bytes were considered.

As F-PCM uses the maximum amount of power at the beginning of each fragment transmission, as well as during the ACK transmission, it forces nodes within the carrier sensing zones (of the sender and receiver) to defer their transmissions, which results in reducing the number of collisions. Therefore, we obtained similar results with different fragment sizes (see Figure 6). However, we observe that the fragment size of 512 bytes produces the highest throughput regardless of the number of nodes. When using a very large fragment size such as 1024 bytes, nodes located within the carrier sensing zones of the sender and receiver can neither participate in sending their data to other

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**Table I. Simulation parameters.**

<table>
<thead>
<tr>
<th>Parameter types</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation-time</td>
<td>20 s</td>
</tr>
<tr>
<td>Terrain-dimensions</td>
<td>(1000 m, 1000 m)</td>
</tr>
<tr>
<td>Number-of-nodes</td>
<td>up to 50 nodes</td>
</tr>
<tr>
<td>MAC protocol</td>
<td>IEEE 802.11b</td>
</tr>
<tr>
<td>MSDU size</td>
<td>2346 bytes</td>
</tr>
<tr>
<td>Source traffic</td>
<td>CBR traffic</td>
</tr>
<tr>
<td>aSlotTime</td>
<td>20 ( \mu \text{s} )</td>
</tr>
<tr>
<td>Fragmentation threshold</td>
<td>512 bytes</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 ( \mu \text{s} )</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 ( \mu \text{s} )</td>
</tr>
</tbody>
</table>

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receiver nodes nor receive data from other sender nodes because their EIFSs are set to large values based upon fragment size, as mentioned in Equation (2). Therefore, we obtained a low throughput. In addition, Figure 6 shows that as the number of nodes increases, the average throughput tends to generally decrease.

In terms of energy consumption, however, a power increase of low frequency for the DATA fragments, as well as that of ACKs causes less energy to be consumed in the network. Figure 7 shows the amount of energy consumption according to the number of nodes. As shown in the figure, as the number of nodes increases (i.e., as the possibility of collisions increases), the performance differences increase. We found that for small fragments, the results are the opposite of those when using large fragments. As a result, we found that a size of 512 bytes is the most adequate in terms of performance.
5.2. Simulation Results Using Chain Topology

First, we compared F-PCM with the other two protocols using chain topologies. We made a chain of nodes by varying the number of nodes between 10 and 50 meters shown in Figure 8, where the distance between the neighboring nodes is uniformly distributed between 10 and 100 meters. The node numbered 1 is the source and the node with the highest number is the destination. Note that the fragment size was fixed to 512 bytes according to the aforementioned simulation results.

With a larger number of nodes in the network, less throughput was obtained due to the presence of more collisions, until packets succeed in arriving at the destination (see Figure 9). In BASIC, more nodes increase the risk. Although they are located within a carrier sensing zone, they perform their transmissions after the EIFS values (set to their NAVs during the RTS–CTS exchange) expire. Hence, the possibility of their transmissions interfering and colliding with the DATA–ACK exchange is higher. This results in a decrease in the end-to-end average throughput.

Although PCM considered the existence of nodes located within a carrier sensing zone of a sender and improved the performance in terms of a lower number of collisions and higher throughput, it did not address the possibility of a collision at the receiver, which can be caused by the existence of nodes located within a carrier sensing zone of a receiver. Regardless of the number of nodes, our F-PCM outperforms BASIC and PCM.

In addition, an increase in collisions means that more energy is consumed due to the high frequency of re-transmissions. Regarding energy consumption, our F-PCM still outperforms BASIC and PCM in all cases (see Figure 10). In summary, F-PCM outperforms PCM in throughput performance and energy consumption by 22% and 11% on average, respectively.

5.3. Simulation Results Using Random Topology

In addition to chain topologies, we investigated the F-PCM performance using random topologies with various number of nodes whose positions are randomly selected. The fragment size was also fixed to 512 bytes. The results represent the average of over 30 simulations. As shown in Figure 11, with a large number of nodes, we obtained low throughput due to the large number of collisions during the channel access among nodes. Even in this random topology, F-PCM performed better than the others regardless of the...
number of nodes. This is due to its ability to reduce the number of collisions at both the sender and receiver positions.

Regarding energy consumption, F-PCM was most economical since it has fewer re-transmissions (see Figure 12). In addition, we also observed that as the number of nodes increased, difference performance also increased. In other words, F-PCM performed better even in a dense network environment where collisions are more severe. In summary, F-PCM performed better in terms of throughput and energy consumption than PCM by 24% and 17% on average, respectively.

5.4. Simulation Results According to Hop Distance

In this simulation, we investigated the end-to-end throughput and the amount of energy expended in the network according to the hop distance between the source and destination nodes. We randomly selected...
a source node among the nodes in the simulation area. One of the nodes, which is \( n \)-hop away from the source node, was chosen as its destination node (In this simulation, \( n \) is increased from 1 to 5). This is different from a chain topology where all nodes are linearly positioned. In this case, many other nodes are located around an acquired path.

Figure 13 shows that F-PCM outperforms the others in terms of a higher throughput, irrespective of the hop distance. It also indicates that when the number of hops is large, we obtained low throughput because it is more difficult to transmit packets to the destination successfully.

Regarding energy consumption, the highest amount of energy can be saved in F-PCM since it requires fewer re-transmissions than the others (see Figure 14). The amount of energy consumed while a packet is successfully transmitted to a far-away destination node is
similar to that when several packets are safely transmitted to a nearby destination node. Therefore, we could not see a significant difference between $n = 1$ and $n = 5$. In summary, F-PCM performed better in terms of throughput and saved more energy than PCM by 42% and 38% on average, respectively.

6. Conclusion

We introduced the F-PCM protocol to reduce collisions that are caused by the existence of an interference range (called carrier sensing zone). F-PCM utilizes the fragmentation technique found in the IEEE 802.11 standard. RTS, CTS, and ACK packets are transmitted with the maximum amount of power, and a large DATA packet is divided into several fragments, which are then transmitted with the required amount of power in order to reach the receiver. In order for the nodes within the carrier sensing zone of a sender to defer their transmissions, the sender uses its transmission power with the maximum amount for a short duration when transmitting each fragment. In addition, in order for the nodes within the carrier sensing zone of a receiver to defer their transmissions, the receiver transmits its ACK packet(s) with the maximum amount of power. This, however, is not applied to the last ACK packet because there is no need to delay their transmissions any longer. Through extensive simulations using random network topologies, we found that the most appropriate fragment size is 512 bytes and that F-PCM outperforms BASIC and PCM, yielding throughput and energy-consumption improvements by 24% and 17% on average, respectively. In particular, F-PCM performed better than other approaches in a dense network environment with a high probability for collisions. Finally, in our work, we derived fragment size through empirical analysis but a more mathematical approach could be used as part of future work. In addition, we plan to consider the presence of mobility and its impact on MAC performance.

References


Authors’ Biographies

Donghyun Kim is a professor with the Department of Computer Engineering, Kyungpook National University, Daegu, Korea. He received the BS degree at Kyungpook National University. He also obtained the MS and PhD degrees at Seoul National University, Korea. He was a visiting researcher at Georgia Institute of Technology. He also performed a post-doctorate program at University of California Santa Cruz. He has been a TPC member of several IEEE conferences. He received the best paper award from the Korean Federation of Science and Technology Societies, 2002. His research interest is ad-hoc network, sensor network and wireless LAN, etc.

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